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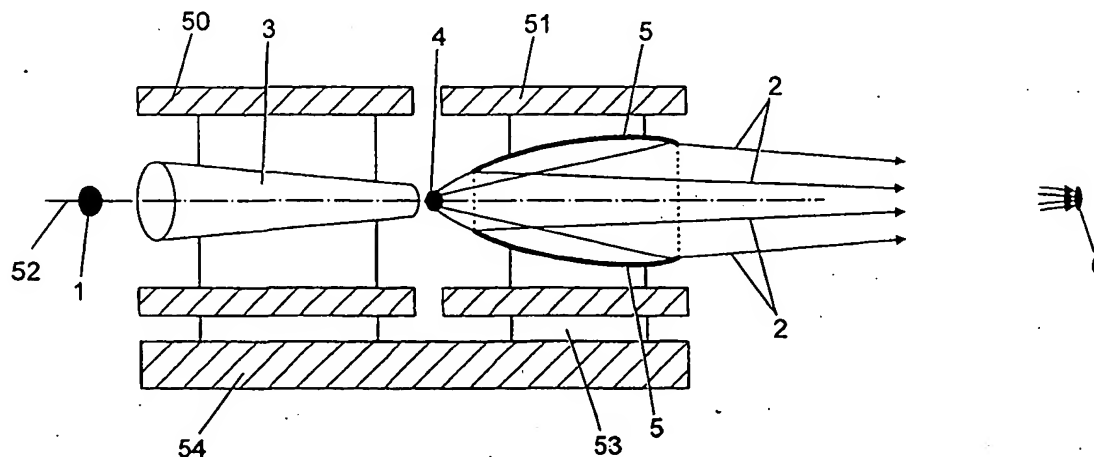
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(21) International Application Number: PCT/GB99/02216 (22) International Filing Date: 23 July 1999 (23.07.99) (30) Priority Data: 9815968.4 23 July 1998 (23.07.98) GB (71) Applicant (for all designated States except US): BEDE SCIENTIFIC INSTRUMENTS LIMITED [GB/GB]; Bowburn South Industrial Estate, Bowburn, Durham DH6 5AD (GB). (72) Inventors; and (75) Inventors/Applicants (for US only): LOXLEY, Neil [GB/GB]; 9 Whitesmocks Avenue, Durham DH1 4HP (GB). PINA, Ladislav [CZ/CZ]; Janovska 373, 109 00 Prague 10 (CZ). (74) Agent: MURGITROYD & COMPANY; 373 Scotland Street, Glasgow G5 8QA (GB).		(81) Designated States: AE, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW, MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, UA, UG, US, UZ, VN, YU, ZA, ZW, ARIPO patent (GH, GM, KE, LS, MW, SD, SL, SZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: X-RAY FOCUSING APPARATUS



(57) Abstract

An X-ray focusing apparatus comprises a waveguide (3) closely coupled to an X-ray focusing mirror (5). The mirror comprises an interior reflecting surface having a rotational axis of symmetry. The waveguide may comprise a tapered polycapillary lens.

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1 **X-RAY FOCUSING APPARATUS**

2

3 This invention relates to X-ray focusing devices for
4 use with X-ray generators and in particular to X-ray
5 focusing devices which utilise capillary and
6 polycapillary lenses in combination with X-ray focusing
7 mirrors for the close coupled focusing of X-ray beams.

8

9 The majority of X-ray generators produce X-ray beams
10 which have a relatively large focal spot or line which
11 requires that the generator utilises a relatively small
12 aperture to restrict beam diameter and divergence.
13 However, the use of small apertures results in a large
14 loss of X-ray intensity.

15

16 It is known that X-ray focusing mirrors may be used in
17 order to focus and thereby increase the intensity of
18 the beam from an X-ray generator. An example of such a
19 focusing mirror is that distributed by Bede Scientific
20 Instruments Ltd under the Trade Mark "Micromirror".
21 "Micromirrors" are now in commercial production and are
22 being used in X-ray generators. The brightness
23 achieved by using the "Micromirror" is comparable to
24 that given by rotating anode generators with total
25 reflection optics.

1 This focusing mirror comprises a cylindrical body
2 having an axially symmetrical passage extending
3 therethrough. There is an aperture at each end of the
4 body which communicates with the passage. The passage
5 has a profile which may be ellipsoidal or paraboloidal
6 in longitudinal section, depending on requirements.
7 An ellipsoidal profile produces a focused beam with
8 varying divergence and focused spot size, while a
9 paraboloidal profile produces an almost parallel,
10 essentially non-divergent beam. The interior
11 reflecting surface is coated in an exceptionally smooth
12 coating of gold or similar in order to provide specular
13 reflectivity. Typically the mirror is made of nickel
14 and is of the order of 30mm in length. The outside
15 diameter of the mirror is typically 6mm. The entry
16 aperture is generally smaller than the exit aperture.

17
18 It is known to use capillary lenses to focus X-rays. A
19 capillary lens conventionally comprises a number of
20 capillary tubes bundled together. A capillary lens is
21 capable of focusing X-ray radiation to a small diameter
22 spot, but suffers from the disadvantage that the
23 focused beam has relatively high divergence. In
24 contrast an X-ray mirror can produce a beam of
25 relatively low divergence.

26
27 In conventional use, a single X-ray focusing mirror is
28 used to focus the source beam and thus produce a gain
29 in intensity from the X-ray generator to the specimen.
30 However X-ray generators provide X-ray beams which have
31 a relatively large focal spot and therefore even when
32 focused by the X-ray focusing mirror the beam will not
33 be as intense as it can be. In addition, tests have
34 shown that the smaller the dimension of the focal spot
35 the greater increase in gain there will be through the
36 X-ray focusing mirror. Thus, the present invention

1 aims to provide apparatus which in combination will
2 provide an input focal point at the entry aperture of
3 the X-ray focusing mirror which has a diameter as close
4 as possible to zero, thereby maximising the gain
5 through the X-ray focusing mirror to the target
6 specimen.

7
8 According to a first aspect of the present invention
9 there is provided an X-ray focusing device comprising a
10 capillary waveguide arranged on a first axis closely
11 coupled to an X-ray focusing mirror, whereby the mirror
12 comprises an interior reflecting surface having a
13 rotational axis of symmetry on a second axis, said
14 first and second axes being substantially collinear.

15
16 It will be understood to those skilled in the art that
17 close coupling involves arranging the components of the
18 focusing device such that the separation between them
19 is of the order of magnitude of the length of each
20 component or less, preferably less than 50 mm, most
21 preferably less than 10 mm.

22
23 Preferably said interior reflecting surface is
24 ellipsoidal, paraboloidal or conical in longitudinal
25 section.

26
27 Preferably said capillary waveguide comprises one or
28 more tapered capillaries arranged symmetrically about
29 said first axis. Preferably the angle of taper of said
30 tapered capillaries is less than 10 mrad.

31
32 Preferably the capillary waveguide is arranged to
33 produce a focused X-ray beam of less than 10 μm
34 diameter.

35
36 According to a preferred embodiment the capillary lens

1 comprises a single tapered capillary having an internal
2 profile adapted to reduce the diameter of the focal
3 spot of an X-ray source.

4
5 According to a second aspect of the present invention
6 there is provided an X-ray focusing device comprising a
7 polycapillary lens arranged on a first axis closely
8 coupled to an X-ray focusing mirror, whereby the mirror
9 comprises an interior reflecting surface having a
10 rotational axis of symmetry on a second axis, said
11 first and second axes being substantially collinear.

12
13 Preferably said interior reflecting surface is
14 ellipsoidal, paraboloidal or conical in longitudinal
15 section.

16
17 Preferably said polycapillary lens comprises a
18 plurality of tapered capillaries arranged such that
19 both the diameter of the focal spot of an X-ray source
20 and the angular divergence of the X-rays are reduced.

21
22 Preferably said capillaries comprises fibres having
23 internal diameters of less than 10 μm , most preferably
24 less than 2 μm .

25
26 Preferably said polycapillary lens comprises between 10
27 and 500, most preferably between 50 and 200 tapered
28 capillaries.

29
30 Preferably said polycapillary lens is arranged such
31 that its overall diameter first increases and then
32 decreases with increasing distance from the X-ray
33 source.

34
35 Preferably, said mirror is moveable in position
36 relative to said waveguide. Preferably, said device

1 further comprises a guide means for guiding said mirror
2 in a direction parallel to the second axis, and
3 adjustment means for adjusting the spacing of the
4 waveguide and the mirror. Preferably, the device also
5 comprises angular adjustment means adapted to allow
6 angular adjustment of the mirror. Alternatively, said
7 mirror is fixed in position relative to said waveguide.

8
9 According to a third aspect of the present invention
10 there is provided an X-ray focusing device comprising a
11 polycapillary lens arranged on a first axis closely
12 coupled to a planar or non-planar X-ray target of an X-
13 ray generator, said polycapillary lens comprising a
14 plurality of tapered capillaries arranged such that the
15 input end of each capillary is arranged substantially
16 normal to the adjacent portion of said X-ray target.
17 The polycapillary lens may be closely coupled to an X-
18 ray focusing mirror at its end remote from the target,
19 in accordance with the first or second aspects of the
20 invention.

21
22 Preferably said polycapillary lens is arranged such
23 that its overall diameter first increases and then
24 decreases with increasing distance from the X-ray
25 source.

26
27 According to a fourth aspect of the present invention
28 there is provided an X-ray generating device comprising
29 an annular electron source arranged about a tapered or
30 conical X-ray target closely coupled to a polycapillary
31 lens or an X-ray focusing mirror. The X-ray target may
32 be coupled to a polycapillary lens, which is itself
33 closely coupled to an X-ray focusing mirror at its end
34 remote from the target, in accordance with the first or
35 second aspects of the invention.

36

1 According to a fifth aspect of the present invention
2 there is provided an X-ray focusing device comprising a
3 substantially hemispherical X-ray target closely
4 coupled to a polycapillary lens or an X-ray focusing
5 mirror, the target comprising a plurality of channels
6 axially orientated towards the hemispherical centre.
7 Preferably the device is positioned such that the
8 electron source is at the hemispherical centre. The X-
9 ray target may be coupled to a polycapillary lens,
10 which is itself closely coupled to an X-ray focusing
11 mirror at its end remote from the target, in accordance
12 with the first or second aspects of the invention.
13 Preferably the lens or mirror is arranged such that the
14 angle of collection of the lens or mirror is the same
15 as the angle subtended by the hemispherical target at
16 the hemispherical centre.

17
18 Embodiments of the invention will now be described, by
19 way of example only, with reference to the accompanying
20 figures, where:

21
22 Fig. 1 shows a first embodiment of the present
23 invention, wherein a Single Tapered Capillary lens
24 (STC) is closely coupled to a X-ray focusing mirror;
25

26 Fig. 2 shows a second embodiment of the present
27 invention, wherein a specifically profiled Tapered
28 Polycapillary lens (TPC) is closely coupled to a X-ray
29 focusing mirror;
30

31 Fig. 3 shows a third embodiment of the present
32 invention, wherein a novel X-ray generator is closely
33 coupled to a TPC;
34

35 Fig. 4 is a graph showing the variation in gain against
36 the reduction in diameter of the source beam;

1 Fig. 5 shows a particular embodiment of the apparatus
2 of Fig. 3 using a tapered conical target;

3

4 Fig. 6 shows a particular embodiment of the apparatus
5 of Fig. 3 using a hemispherical microchannel target;
6 and

7

8 Fig. 7 shows a section along line VII-VII of the
9 microchannel target of the apparatus of Fig. 6.

10

11 With reference to Fig. 1, a first embodiment of the
12 present invention is shown, wherein an X-ray generator
13 (not shown) produces an X-ray source 1 on a target of a
14 particular dimension. A single tapered capillary (STC)
15 3 acts as a waveguide and is positioned close to the
16 source 1 to collect the X-rays from the source 1. The
17 STC 3 produces a "virtual" focus 4 at the exit aperture
18 of the STC. An X-ray focusing mirror 5 is closely
19 coupled to the "virtual" focus point 4 to produce a
20 focused X-ray beam 2 which is focused to a focal point
21 6.

22

23 The schematic arrangements for the housing of the STC
24 lens 3 and mirror 5 can also be seen. The STC lens 3
25 and mirror 5 are aligned with each other and are fixed
26 within separate cylindrical housings 50,51. The
27 housings 50,51 may further be contained in an outer
28 housing (not shown) which may be partially evacuated.
29 The apparatus allows alignment of the mirror 5 relative
30 to the STC lens 3 along the beam axis 52 by means of a
31 control mechanism 53. Alignment of the whole assembly
32 relative to the X-ray source 1 is possible by means of
33 a control mechanism 54.

34

35 The control mechanisms 53,54 allow fine adjustment of
36 the position of the housing 51 and also the whole

1 assembly in the x, y, and z directions so that the axis
2 of the mirror 5 is accurately aligned with the X-ray
3 source 1. The mechanisms 50,51 may comprise any
4 suitable mechanisms which permit fine translational
5 adjustment, such as lead screws or Vernier controls.
6

7 As shown in Fig. 4, as the diameter of the focal spot 4
8 decreases, the gain in intensity through the X-ray
9 focusing mirror 5 increases significantly, especially
10 when the diameter of the focal spot 4 is less than 25
11 μm . Whilst there is a significant loss of intensity
12 through the STC lens 3, tests have shown that the
13 increased gain in intensity from the X-ray focusing
14 mirror 5 is higher than the losses in the STC lens 3.
15 In addition, the use of an STC lens 3 also allows the
16 X-ray generator to run with a larger focal spot at the
17 X-ray source (typically 100 μm) and at higher powers
18 than are presently possible, giving a ten fold increase
19 in X-ray brightness.
20

21 The combination of increased power loading and
22 increased mirror efficiency more than balances the
23 losses in the STC lens 3 and produces a net gain of one
24 order of magnitude in intensity when compared to the
25 situation in which the X-ray focusing mirror 5 alone is
26 coupled directly to the X-ray source of the X-ray
27 generator. It is envisaged that the X-ray focusing
28 mirrors may be used with standard sealed tube and
29 rotating anode sources.
30

31 The STC has a tapering internal profile such that the
32 focal spot dimensions of the X-ray source 1 are
33 reduced. The entry diameter of the capillary is of the
34 same magnitude as the diameter of the source, typically
35 100 μm , while the exit diameter of the capillary should
36 be as small as possible, typically 10 μm or less. The

1 angle of convergence of the capillary should be kept as
2 small as possible to minimise X-ray losses through the
3 capillary walls. Typically the angle of convergence
4 should be 10 mrad or less. The angle of convergence
5 may be uniform (ie linear tapering) or the longitudinal
6 profile may be ellipsoidal.

7
8 The entry aperture of the mirror 5 is optimally placed
9 at a distance from the exit aperture of the capillary
10 which is equal to the input focal length of the mirror.
11 The input focal length of the reflecting mirror should
12 be a minimum.

13
14 The use of the mirror 5 and the capillary 3 in
15 combination leads to a net gain in the brightness of
16 the X-ray beam at the focus 6 of the mirror 5 since the
17 mirror focuses much more efficiently with smaller focal
18 spot 4 dimensions. In addition the use of the mirror 5
19 and the capillary 3 in combination allows a larger
20 diameter X-ray source to be used, leading to a higher
21 power loading of the X-ray target and a higher total
22 energy delivered to the focus 6 of the mirror 5.

23
24 With reference to Fig. 2, a second embodiment of the
25 present invention is shown, wherein an X-ray generator
26 (not shown) produces an X-ray source 1 on a target. A
27 "bottle-shaped" tapered polycapillary (TPC) lens 6 acts
28 to both reduce the spatial size of the focal spot from
29 the X-ray source 1 and to reduce the angular divergence
30 of the X-rays. The TPC lens 6 is close coupled to an
31 X-ray focusing mirror 5 and produces a "virtual" focus
32 4, which is then focused by the X-ray focusing mirror 5
33 as a focused X-ray beam 2 to the specimen (not shown).
34 This second embodiment uses similar housings and
35 adjustment means to those shown in Fig. 1, and are not
36 described further.

1 The gain of this second embodiment is produced by three
2 effects, namely:

- 3 (i) a higher power loading on the X-ray generator
4 target (not shown) due to the larger allowable X-ray
5 generator tube focal spot 1,
6 (ii) a higher solid angle of collection of the X-ray
7 beam 2 from the TPC lens 6 than from the X-ray focusing
8 mirror 5 alone, and
9 (iii) a lower divergence of the rays ("natural"
10 divergence from a capillary is around 0.4°) and a
11 smaller focal spot dimension which maximises the gain
12 through the X-ray focusing mirror 5.

13
14 The approximate gains from the second embodiment are a
15 four fold increase from the increased tube target power
16 loading, a three fold increase due to the smaller,
17 lower divergence spot 4 delivered to the X-ray focusing
18 mirror 5, and a five fold increase due to the higher
19 solid angle of collection on the TPC lens 6 (allowing
20 for losses in the TPC lens 6).

21
22 Typically the source 1 is about $100\text{ }\mu\text{m}$ in diameter,
23 while the virtual focus is less than $10\text{ }\mu\text{m}$ in diameter.
24 In one example the TPC lens comprises about 100 fibres
25 arranged in a bundle with an overall diameter of
26 between 100 and $200\text{ }\mu\text{m}$ at entry, increasing to between
27 200 and $400\text{ }\mu\text{m}$ at an intermediate point and tapering to
28 2 to $15\text{ }\mu\text{m}$ at exit. Each individual fibre making up
29 the TPC has an inner diameter which varies from 1 to $40\text{ }\mu\text{m}$. Polycapillary lenses comprised of individual
30 capillaries with diameters of around $10\text{ }\mu\text{m}$ are
31 commercially available now. With improvements to
32 current technology it is reasonable to expect that
33 capillary diameters of less than $10\text{ }\mu\text{m}$ can be achieved.

34
35
36 With reference to Fig.3, a third embodiment of the

1 present invention is shown, wherein a novel design of
2 X-ray generator 10 is closely coupled to an X-ray optic
3 in the form of a TPC lens 6 similar to that shown in
4 the second embodiment of the present invention. The X-
5 ray generator 10 comprises an electron gun 11 producing
6 accelerated electron beams 22 through a Wehnelt grid 13
7 and a transmission target 12 thus producing X-rays 70.
8 The target 12 has a surface which is curved in two
9 perpendicular directions. It is to be understood that
10 the surface may be curved in only one axis or indeed
11 may be substantially planar or composed of a number of
12 planar or curved portions in the form of a polyhedron.
13 The tapered polycapillary lens is close coupled to the
14 target 12, and a gas flow 14 is introduced between the
15 target 12 and the TPC lens 6 in order to provide
16 cooling for the target 12. A possible variation of
17 this third embodiment would be the direct coupling of
18 the X-ray generator 10 to an X-ray focusing mirror 5,
19 which would also deliver significant gains.

20
21 The X-ray generator 10 of the third embodiment is
22 located within a housing 56 and powered via a high
23 voltage connector 55. To provide insulation, the X-ray
24 generator 10 is provided with both insulator plates 58,
25 which may be manufactured from either glass or a
26 ceramic material, and also an insulating potting
27 compound 57 located between the housing 56 and the X-
28 ray generator 10.

29
30 The TPC lens 6 is located within an optics housing 59
31 adjacent the generator housing 56. The TPC lens 6 is
32 held within the optics housing 59 by way of a number of
33 adjustable mountings 60, which permit the position of
34 the TPC lens 6 to be adjusted in the x, y, and z
35 directions so that the lens 6 is accurately aligned
36 with the X-ray source.

1 This third embodiment produces gain by spreading the X-
2 ray source over a much greater surface area which
3 thereby allows for much higher power loading, whilst
4 still retaining the gain of the X-ray optic 6. In this
5 way it is possible to produce extremely simple, compact
6 high power X-ray generators. In addition, the X-ray
7 optic 6 can be tailored to deliver a beam 2 of varying
8 spatial and angular characteristics, which may then be
9 coupled to an X-ray focusing mirror 5 in the manner
10 described in the first and second embodiments.

11

12 In the apparatus according to the third embodiment a
13 point source at a given distance from an x-ray optic,
14 such as the polycapillary lens, can be replaced by an
15 extended source next to the optic, provided the solid
16 angle of collection is the same. Whilst extending the
17 source in this way does not increase the efficiency of
18 the optic per se, it allows each part of the extended
19 source to operate at a power loading (power per unit
20 area) of the same order of magnitude as the power
21 loading of a smaller "point" source. Because the
22 extended source has a larger area allowing a total
23 power of typically several kW, compared to a typical
24 point source of 25 W, the generator can run at much
25 higher operating powers.

26

27 In the example of Fig. 3 the target 12 is shaped as
28 part of a hemisphere. Other geometries are possible,
29 for example the target may be shaped as a truncated
30 cone, as shown in Fig. 5. The entry aperture of the
31 PCL has a shape which corresponds to that of the
32 target.

33

34 The embodiment of Fig. 5 uses an annular filament 30 as
35 an electron source. The filament 30 fires electrons 31
36 onto a tapered target 32 which is shown as a truncated

1 cone which is encircled by the coaxial circular annular
2 filament 30. The optic (PCL or X-ray focusing mirror)
3 6 is close coupled to the target 32, which may be
4 cooled by water 33. The filament 31 and target 32 are
5 located in a vacuum 65 which is enclosed by an annular
6 ceramic disk 63, whilst the generated X-rays 70 exit
7 through an annular beryllium exit window 64 in order to
8 maintain the vacuum 65.

9
10 As with the previous embodiments, the generator is
11 located within a housing 62 and is powered via a high
12 voltage connector 61. The optic 6 is also housed in an
13 optics housing 66 which is similar to those described
14 in the other embodiments, with adjustable mountings 60
15 for adjustment of the optic 6 in the x, y, and z
16 directions.

17
18 The embodiment of Fig. 6 is located in a housing 56
19 such as that described in Fig. 3, and uses as a target
20 a hemispherical microchannel plate 40 coated with
21 target material and held in place by a plate holder 67.
22 The plate 40 comprises a number of capillaries or
23 channels 41, seen more clearly in Fig. 7, which
24 themselves form targets and direct the x-rays 70 caused
25 by the incidence of the electrons on the surface of the
26 target towards the close coupled optic 6.
27 Alternatively the outer surface 42 only of the plate 40
28 may be coated with target material. So as to maintain
29 the vacuum within the tube housing 56, a curved
30 beryllium window 68 is attached to the housing 56.

31
32 These and other modifications and improvements can be
33 incorporated without departing from the scope of the
34 invention.

1 CLAIMS:

2

3 1. An X-ray focusing device comprising a waveguide
4 arranged on a first axis closely coupled to an X-ray
5 focusing mirror, whereby the mirror comprises an
6 interior reflecting surface having a rotational axis of
7 symmetry on a second axis, said first and second axes
8 being substantially collinear.

9

10 2. An X-ray focusing device according to Claim 1,
11 wherein said waveguide is a capillary waveguide
12 comprising one or more tapered capillaries arranged
13 symmetrically about said first axis.

14

15 3. An X-ray focusing device according to Claim 2,
16 wherein the angle of taper of said tapered capillaries
17 is less than 10 mrad.

18

19 4. An X-ray focusing device according to either Claim
20 2 or Claim 3, wherein the capillary waveguide is
21 arranged to produce a focused X-ray beam of less than
22 10 μ m diameter.

23

24 5. An X-ray focusing device according to Claim 1,
25 wherein said waveguide is a polycapillary lens.

26

27 6. An X-ray focusing device according to Claim 5,
28 wherein said polycapillary lens comprises a plurality
29 of tapered capillaries arranged such that both the
30 diameter of the focal spot of an X-ray source and the
31 angular divergence of the X-rays are reduced at a
32 sample point.

33

34 7. An X-ray focusing device according to Claim 6,
35 wherein said capillaries comprise tubes having internal
36 diameters of less than 10 μ m.

- 1 8. An X-ray focusing device according to Claim 7,
2 wherein said capillaries comprise tubes having internal
3 diameters of less than $2\mu\text{m}$.
4
- 5 9. An X-ray focusing device according to any of
6 Claims 6 to 8, wherein said polycapillary lens
7 comprises between 10 and 500 tapered capillaries.
8
- 9 10. An X-ray focusing device according to Claim 9,
10 wherein said polycapillary lens comprises between 50
11 and 200 tapered capillaries.
12
- 13 11. An X-ray focusing device according to any of
14 Claims 6 to 10, wherein said polycapillary lens is
15 arranged such that its overall diameter first increases
16 and then decreases with increasing distance from the X-
17 ray source.
18
- 19 12. An X-ray focusing device according to any
20 preceding claim, wherein said mirror is moveable in
21 position relative to said waveguide.
22
- 23 13. An X-ray focusing device according to Claim 12,
24 wherein the device further comprises a guide means for
25 guiding said mirror in a direction parallel to the
26 second axis, and adjustment means for adjusting the
27 spacing of the waveguide and the mirror.
28
- 29 14. An X-ray focusing device according to either Claim
30 12 or Claim 13, wherein said device further comprises
31 angular adjustment means adapted to allow angular
32 adjustment of the mirror.
33
- 34 15. An X-ray focusing device according to any of
35 Claims 1 to 11, wherein said mirror is fixed in
36 position relative to said waveguide.

1 16. An X-ray focusing device according to any of
2 Claims 5 to 11, wherein the polycapillary lens is
3 closely coupled to an X-ray target of an X-ray
4 generator, said polycapillary lens comprising a
5 plurality of tapered capillaries arranged such that the
6 input end of each capillary is arranged substantially
7 normal to the adjacent portion of said X-ray target.
8

9 17. An X-ray focusing device according to Claim 16,
10 wherein said X-ray target is planar.
11

12 18. An X-ray focusing device according to Claim 16,
13 wherein said X-ray target is non-planar.
14

15 19. An X-ray focusing device according to any of
16 Claims 16 to 18, wherein said polycapillary lens is
17 arranged such that its overall diameter first increases
18 and then decreases with increasing distance from the X-
19 ray source.
20

21 20. An X-ray generating device comprising an annular
22 electron source arranged about an X-ray target closely
23 coupled to an X-ray focusing device according to any
24 one of Claims 1 to 15.
25

26 21. An X-ray generating device according to Claim 20,
27 wherein said X-ray target is tapered.
28

29 22. An X-ray generating device according to Claim 20,
30 wherein said X-ray target is conical.
31

32 23. An X-ray generating device according to Claim 21
33 or 22, wherein said X-ray target acts as said waveguide
34 and directs the X-ray to the X-ray focusing mirror.
35

36 24. An X-ray generating device comprising a

1 substantially hemispherical X-ray target closely
2 coupled to an X-ray focusing device according to any of
3 Claims 1 to 15, the target comprising a plurality of
4 channels axially orientated towards the hemispherical
5 centre.

6
7 25. An X-ray generating device according to Claim 24,
8 further comprising an electron source positioned at the
9 hemispherical centre of the X-ray target.

10

11 26. An X-ray generating device according to either
12 Claim 24 or Claim 25, wherein the focusing device is
13 arranged such that the angle of collection of the
14 focusing device is the same as the angle subtended by
15 the hemispherical target at the hemispherical centre.

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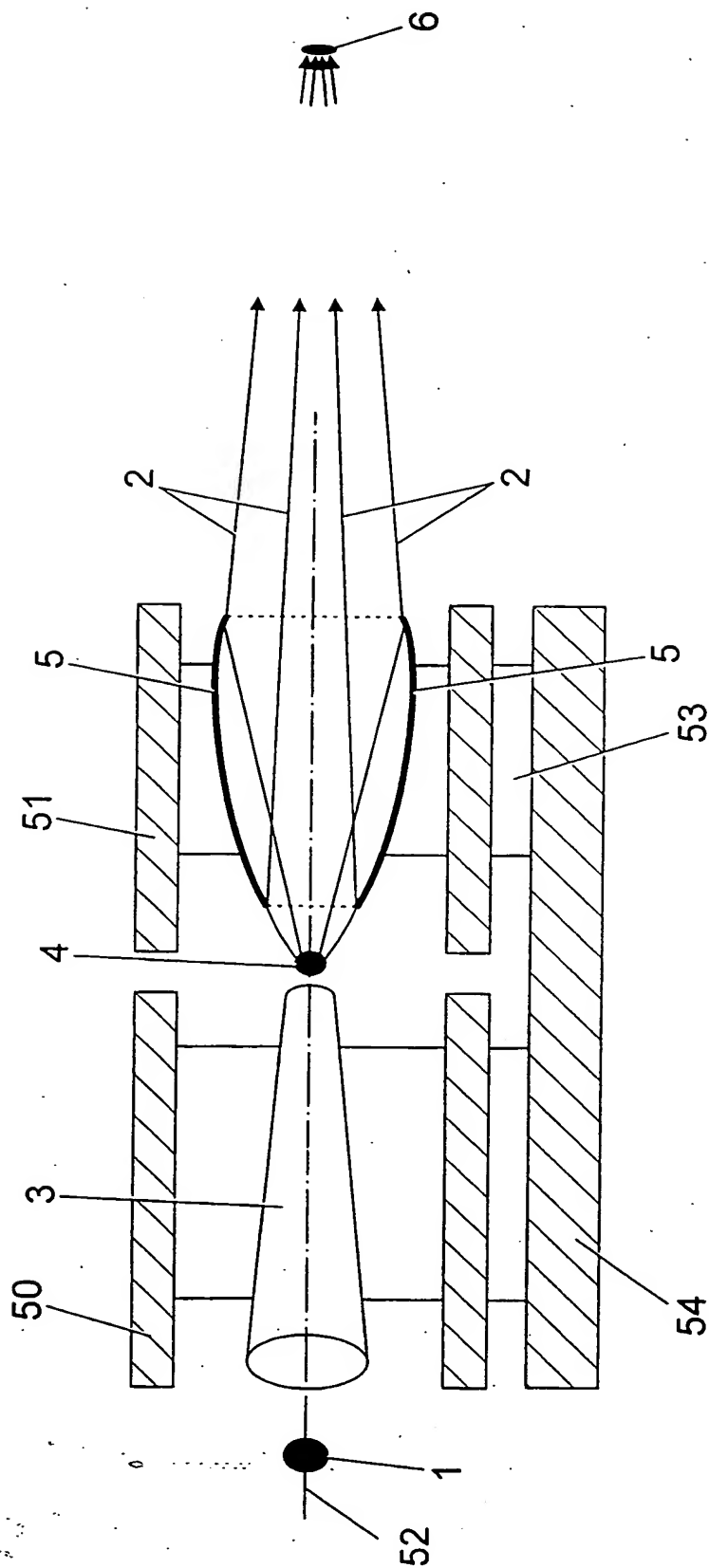


Fig. 1

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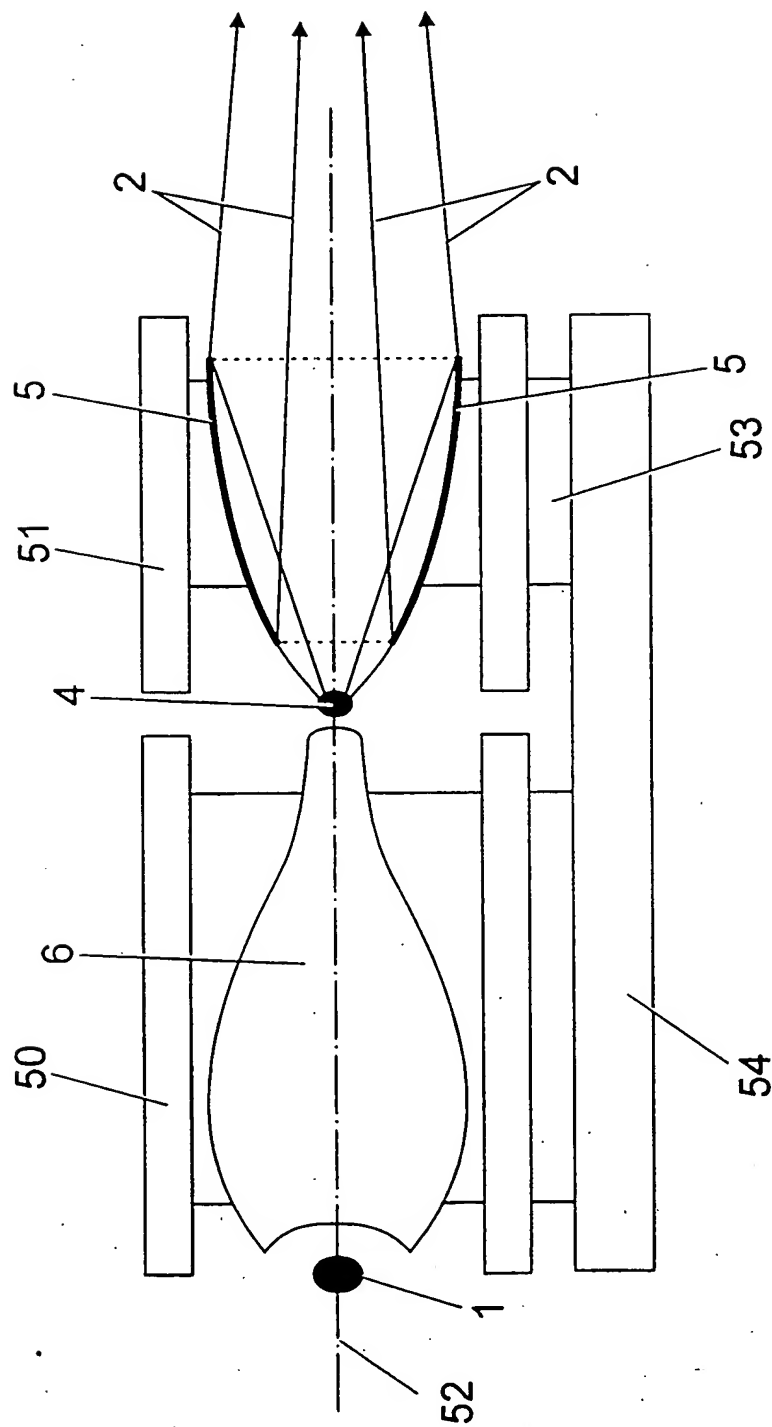


Fig. 2

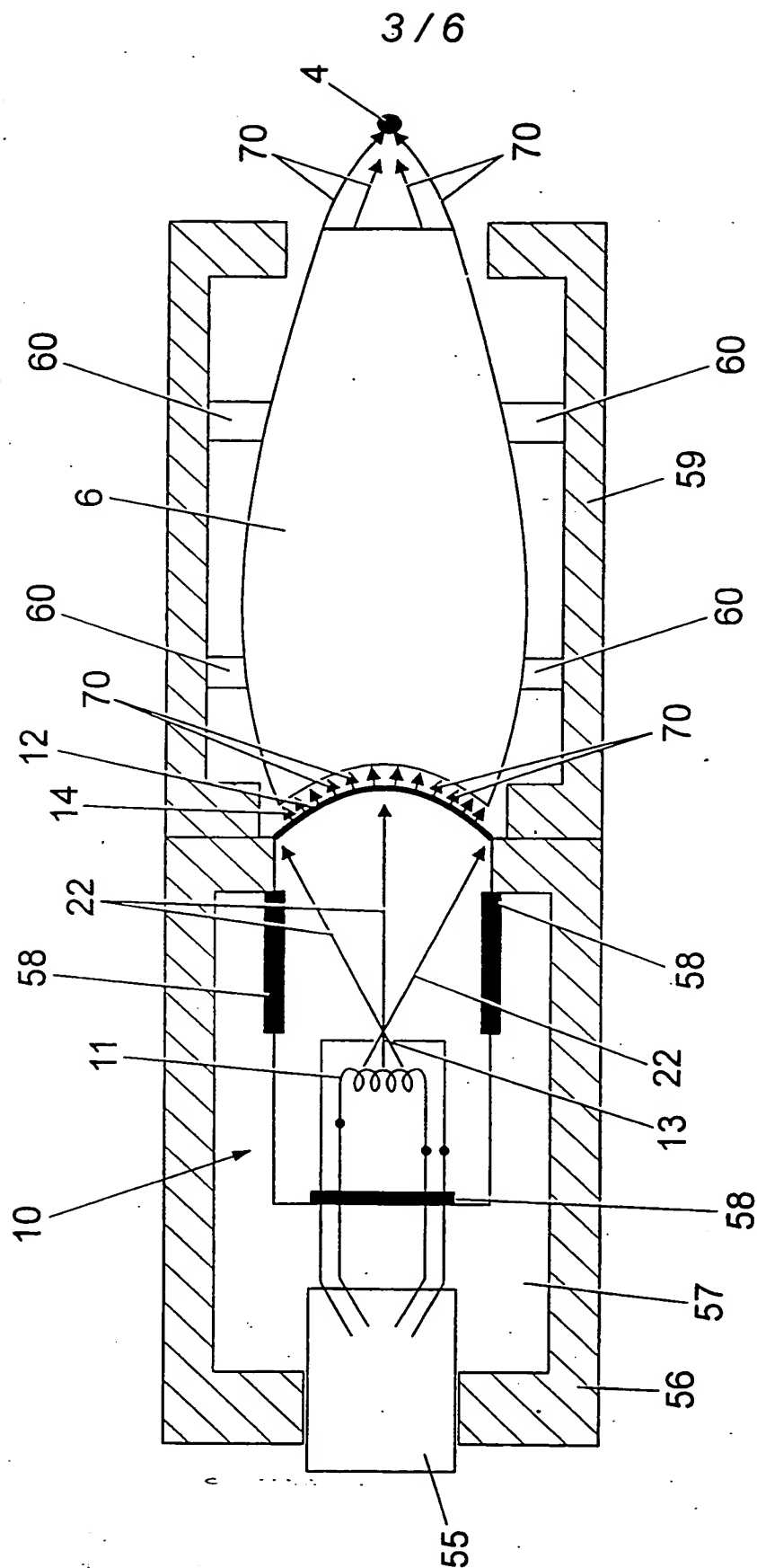


Fig. 3

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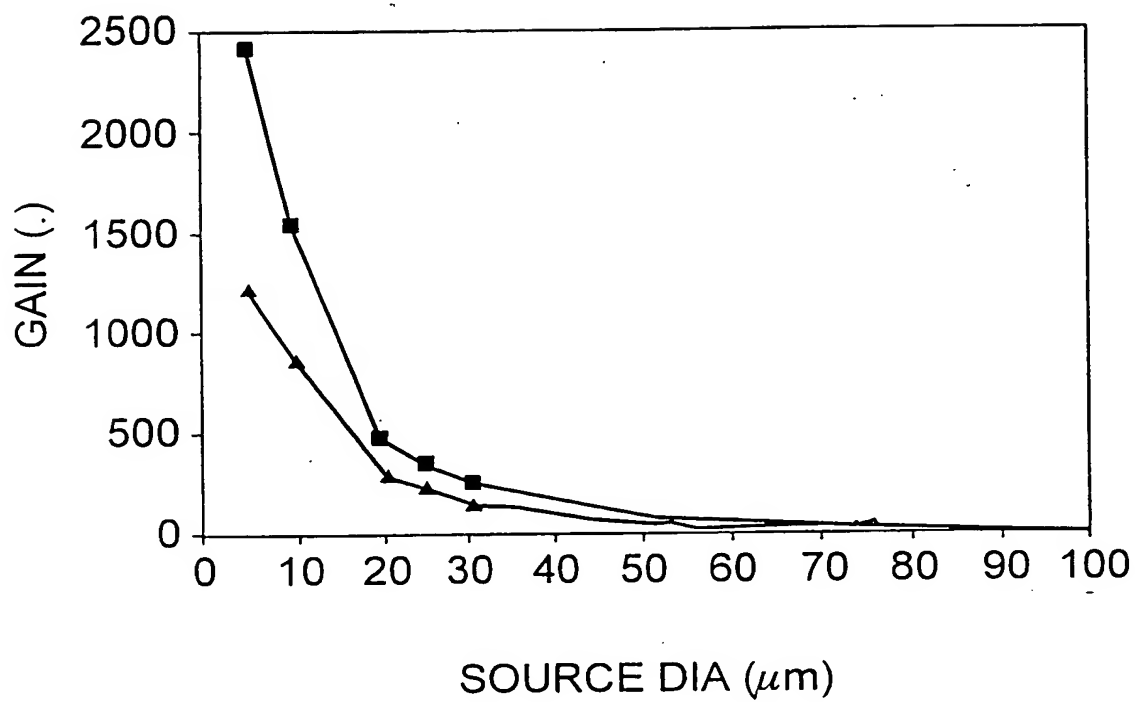


Fig. 4

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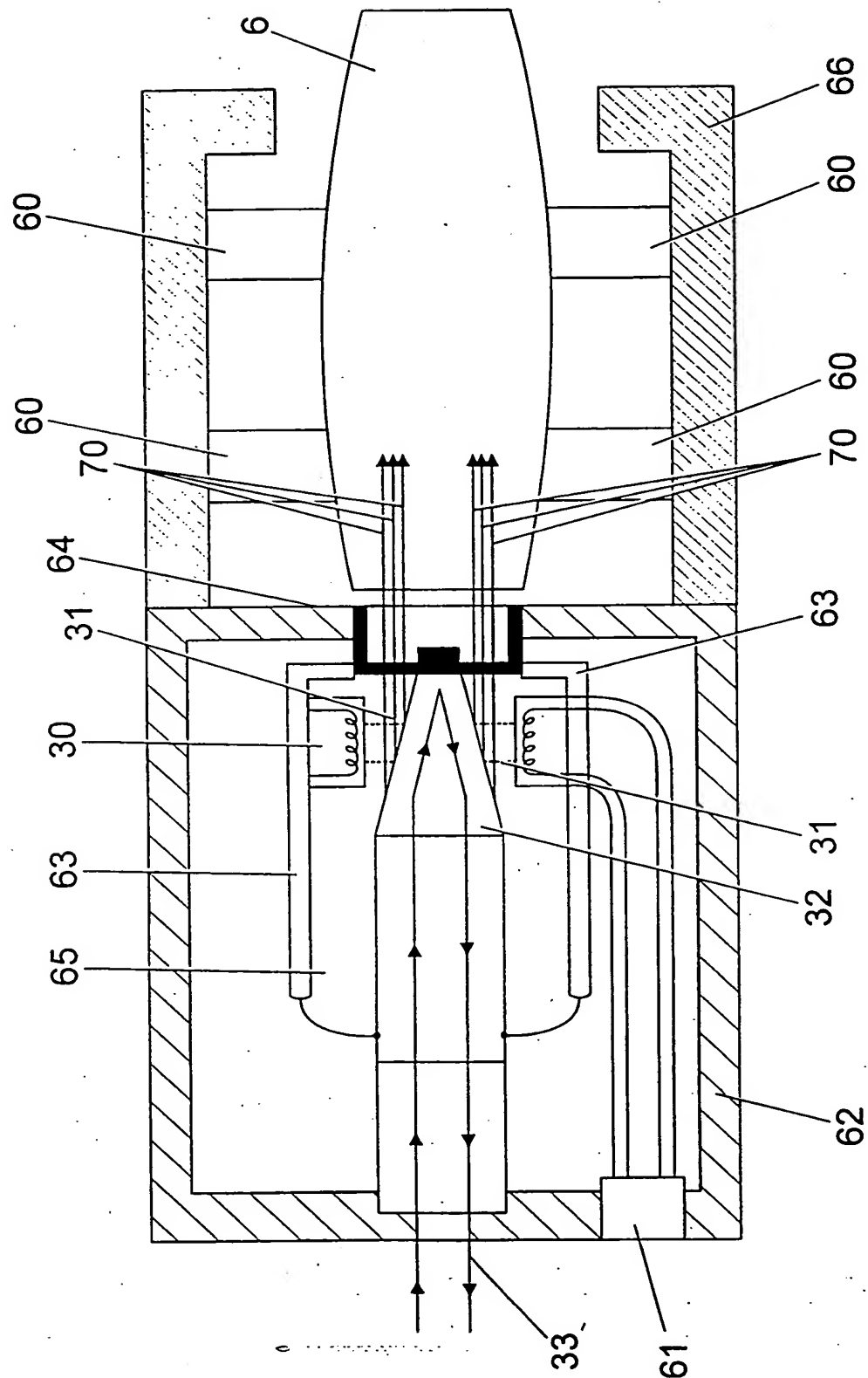
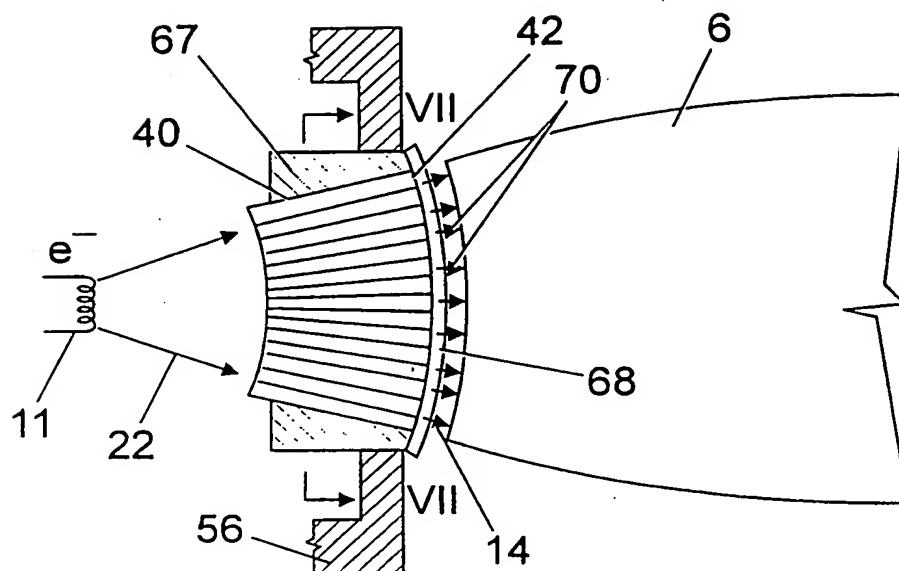
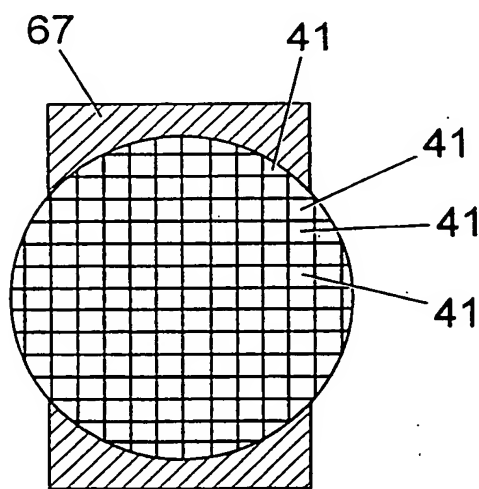


Fig. 5

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*Fig. 6**Fig. 7*

INTERNATIONAL SEARCH REPORT

International Application No

PCT/GB 99/02216

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G21K1/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 G21K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 192 869 A (KUMAKHOV) 9 March 1993 (1993-03-09) the whole document ---	1-26
A	US 5 747 821 A (YORK ET AL.) 5 May 1998 (1998-05-05) the whole document ---	1-26
A	US 5 604 353 A (GIBSON ET AL.) 18 February 1997 (1997-02-18) the whole document ---	1-26
A	US 4 525 853 A (KEEM ET AL.) 25 June 1985 (1985-06-25) the whole document ---	1, 20, 24
	--- -/--	

☒ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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Date of the actual completion of the international search

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INTERNATIONAL SEARCH REPORT

International Application No

FJI/GB 99/02216

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 222 113 A (THIEME ET AL.) 22 June 1993 (1993-06-22) abstract; figure 1	1,20,24
A	----- PATENT ABSTRACTS OF JAPAN vol. 13, no. 361, 11 August 1989 (1989-08-11) & JP 01 119800 A (FUJITSU LTD) abstract -----	1,20,24

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

101/GB 99/02216

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 5192869	A	09-03-1993	AT 164257 T	15-04-1998
			AU 9032291 A	26-05-1992
			CA 2095222 A	01-05-1992
			DE 9117302 U	21-10-1999
			DE 69129117 D	23-04-1998
			DE 69129117 T	06-08-1998
			EP 0555376 A	18-08-1993
			JP 7504491 T	18-05-1995
			WO 9208235 A	14-05-1992
			US 5497008 A	05-03-1996
			US 5175755 A	29-12-1992
US 5747821	A	05-05-1998	NONE	
US 5604353	A	18-02-1997	AU 6383996 A	09-01-1997
			CN 1192821 A	09-09-1998
			EP 0832491 A	01-04-1998
			JP 11502933 T	09-03-1999
			WO 9642088 A	27-12-1996
US 4525853	A	25-06-1985	AU 562603 B	11-06-1987
			AU 3288084 A	26-04-1985
			CA 1223092 A	16-06-1987
			EP 0138440 A	24-04-1985
			IL 72868 A	30-06-1988
			JP 60098399 A	01-06-1985
US 5222113	A	22-06-1993	DE 4027285 A	05-03-1992
			AT 134065 T	15-02-1996
			DE 59107380 D	21-03-1996
			EP 0475098 A	18-03-1992
			JP 4262300 A	17-09-1992
JP 01119800	A	11-05-1989	NONE	